Application Note 812

New Frequency Control Technologies:

A Comparative Analysis of New Technologies and Traditional
Quartz Based Technology

September 6, 2012

1. Introduction

Over the years there has been a steady progression in the development of frequency control technologies. While many changes have been the result of the natural evolution of technology, the main drivers have been enhanced manufacturing capabilities, demands to reduce costs, and various technical requirements for smaller sizes, greater stability, reduced power consumption, and faster start-up.

Quartz-based devices, primarily Bulk Acoustic Wave (BAW) devices, have long been the standard by which all commercially available clocking sources have been compared. The history of quartz crystals as very stable, high quality resonators for frequency control is well documented and universally recognized. Frequency versus temperature response, aging, jitter and phase noise characteristics of quartz-based frequency control devices are all well chronicled in the industry. However, a concise technical comparison of such characteristics with frequency control devices utilizing new technologies has been lacking. To establish a benchmark between MEMS and other devices against established quartz based devices, the authors of this analysis began a study in 2007, and published *A Comparative Analysis of Frequency Control Devices* in 2008. This comparison study is an update and expansion of the earlier benchmark analysis.

2. Devices Studied and Methodology

This study applied standard measurement techniques under the same test conditions for the following devices in order to provide a direct comparison of performance and capability:

I MEMS I oscillators (manufacturer A)
II MEMS II Oscillators (manufacturer B)
III Programmable M/N Multiplier Oscillators with quartz crystals as resonators (manufacturer C)
IV Quartz Free Oscillators – Temperature-compensated L/C oscillators without any external resonators (manufactured by Pletronics, Inc., Series QF55)
V Traditional Quartz (Bulk Acoustic Wave) Clock Oscillators (manufactured by Pletronics, Inc., Series SM55)

All of the devices studied were purchased from a national distributor of electronic components and are readily available commercially. Parts manufactured by Pletronics, Inc. were taken from factory inventory.

The results presented here are based upon established frequency control measurement techniques that employed the current testing technology commercially available at the time the devices were studied in 2012. All of the tests were performed under identical conditions unless otherwise noted.

3. Electrical Characteristics Studied

The following electrical characteristics were compared.

1. **Frequency vs. Temperature and Hysteresis**
2. **Phase Noise / Jitter**
3. **Start-up Time**
4. **Supply Current (Current Draw)**
5. **Short-term Stability**
6. **Long-term Stability (Aging)**

Frequency vs. Temperature - Hysteresis

All of the oscillators were continuously powered during testing. All were tested at 1.0°C step size in the same test system at the same time. The data was taken in the cold-to-hot and hot-to-cold direction to indicate and evaluate if any hysteresis exists. Oscillator hysteresis is here defined as the deviation between the Frequency vs. Temperature curve measured when the temperature is swept from hot to cold temperatures and when the temperature is swept from cold to hot temperatures.

The hysteresis data are given in Fig. 1, 2, 3, 4, & 5 and the summary data in Table 1.

NOTE: Please note the vertical scales (Y-axis) are all different in fig #1 – Fig #5. The magnitude of the hysteresis shown in these figures should be interpreted in the context of the frequency stability specification of each device. For example, one device is specified at +/- 2.5 ppm while another at +/- 100 ppm.

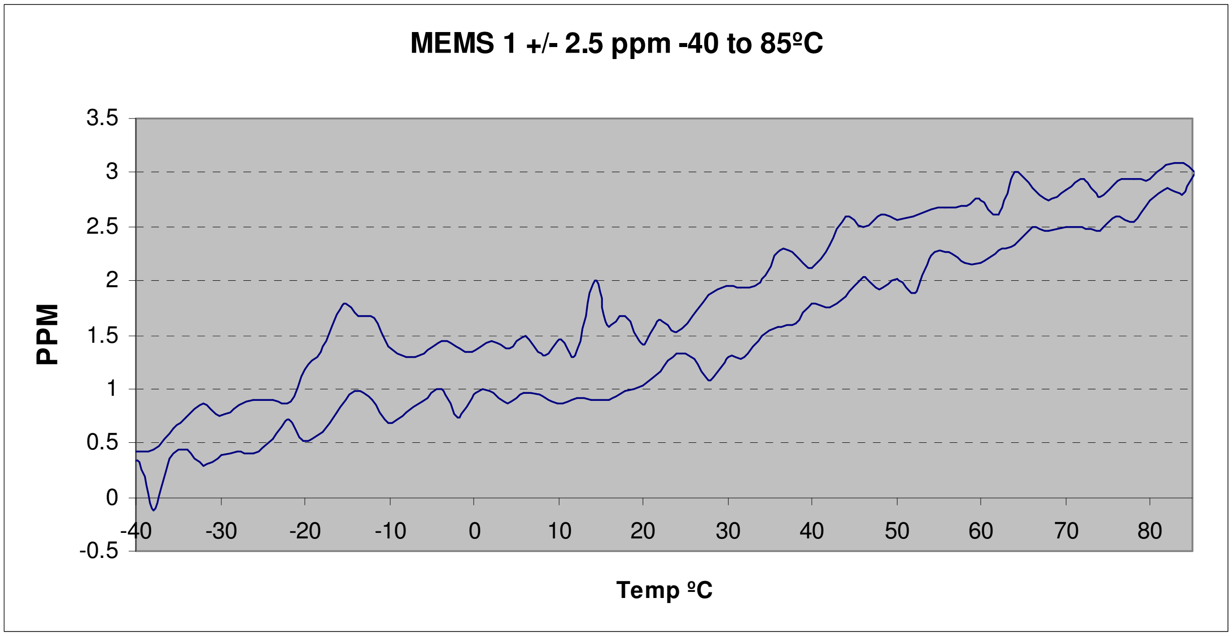

Fig. # 1

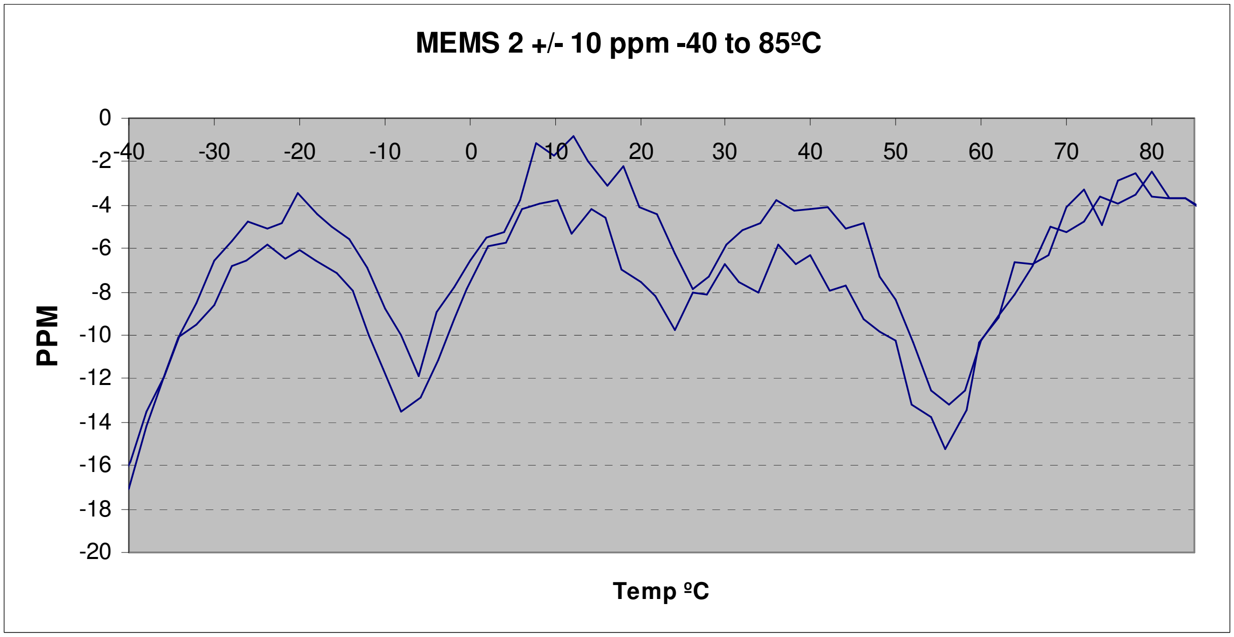
MEMS 2 +/- 10 ppm -40 to 85ºC
PPM
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
Temp ºC

Fig. # 2

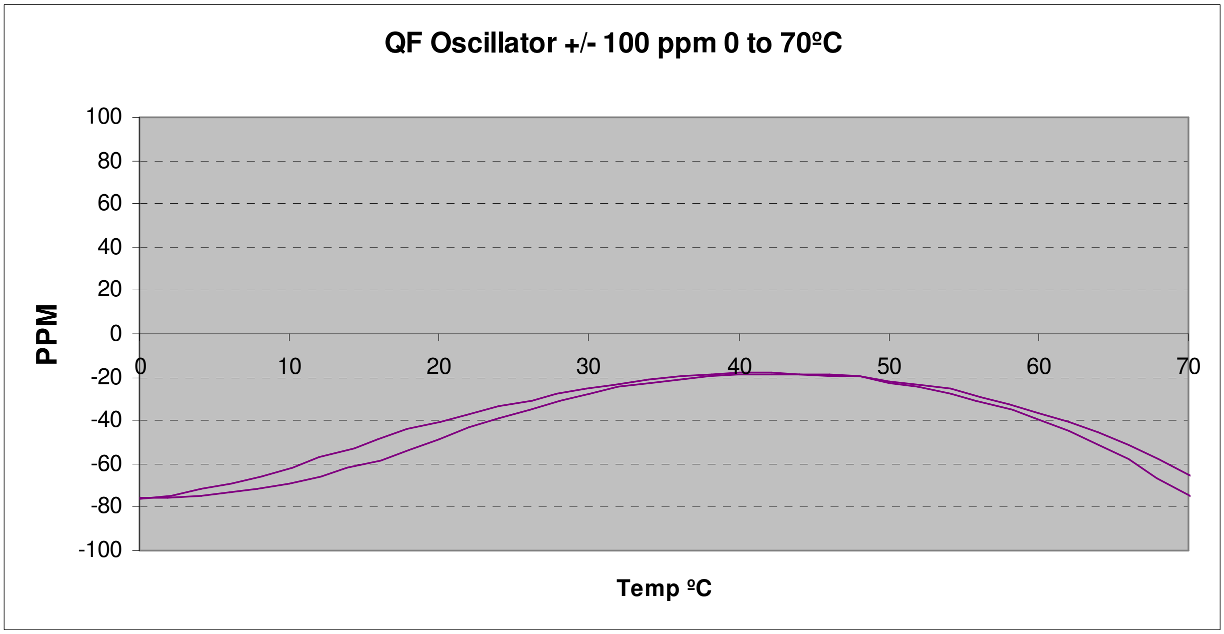
QF Oscillator +/- 100 ppm 0 to 70ºC
PPM
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
10
20
30
40
50
60
70
Temp ºC

Fig. # 3

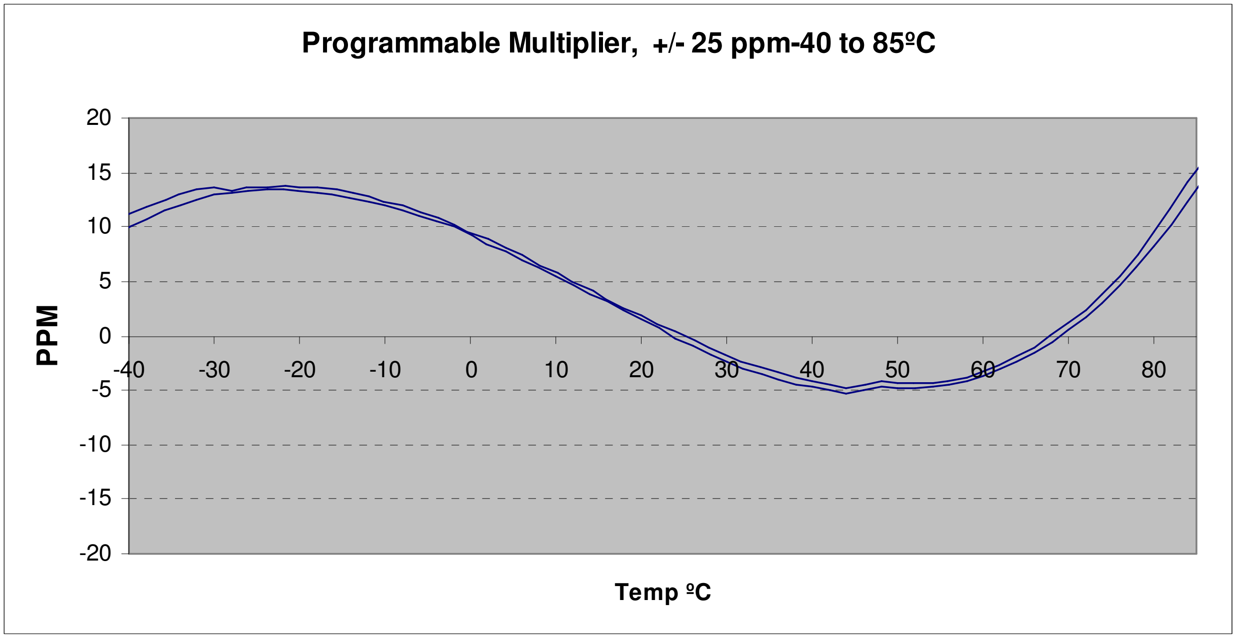

Fig. # 4

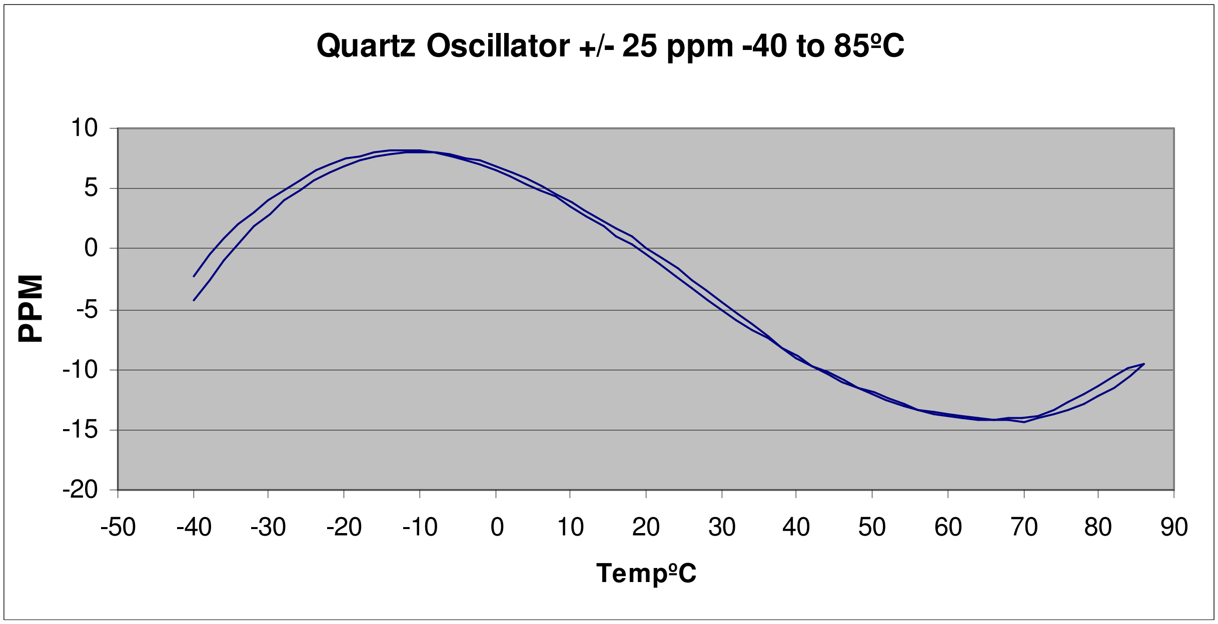

Fig. # 5

Phase Noise / Jitter

Phase Noise, from which jitter is calculated is a cause for concern among design engineers working in sensitive wireless applications. Phase noise is defined as the frequency domain short-term fluctuations in the phase of a waveform, caused by instabilities in the time domain. The common term for instabilities in the time domain is jitter. Generally speaking, radio frequency engineers speak of the phase noise of an oscillator, whereas digital system engineers work with the jitter of a clock. The measurement conditions were as follows:

- Agilent 5500/5052 phase noise test system used;
- Measured at manufacturer's specified supply voltage;
- 10 minute stabilization time was allowed before measurement of each device.

The phase noise data are given in Fig. 6 and the summary of jitter data in Table 1.

NOTE: The elevated phase noise of the MEMS oscillators is possibly the result of the relatively lower Q of the MEMS resonators. The phase noise of QF oscillators is the worst in the close-in range but comparable to the phase noise of other technologies in the 12 kHz-20 MHz range.

Start-up Start-Time

Start-up Time is defined as the time period between the time the power supply is turned on and the time the unit reaches the full amplitude and frequency. The power supply was turned on with the equivalent of a debounced moment switch. The summary data are given in Table 1.

NOTE: While there is some variance in start-up time between the different devices studied, all appear to be at or near the requirements of most commercial requirements. All are considerably faster than ovenized oscillators (OCXO's).

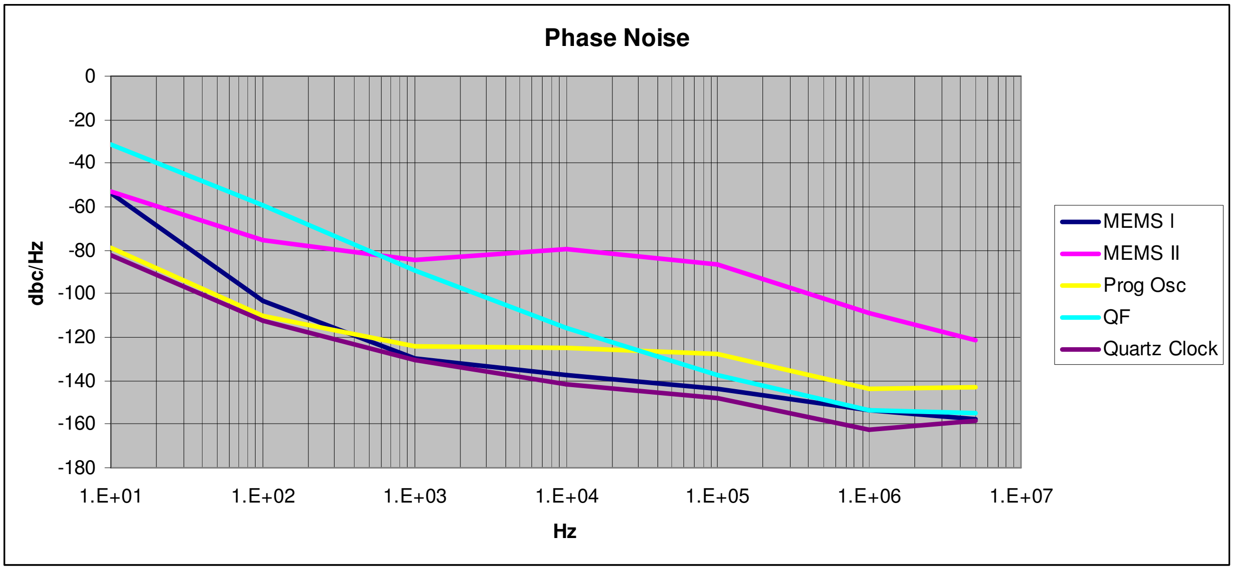

Fig #6

Supply Current (Current Draw)

Increasingly, supply current has become an issue for many design engineers working on both battery powered and traditional devices. The summary data are given in Table 1.

NOTE: MEMS and programmable oscillators tend to draw more current than quartz-based oscillators and QF oscillators.

Short-term Stability

The short term stability is defined here as frequency measurements taken every 0.1 seconds for 8 minutes with the DUT stabilized at 25° C. The devices were tested with an Agilent 53152 frequency counter connected directly to a rubidium atomic frequency standard reference. The data are given in Fig.7, 8, 9, 10 & 11 and the summary data in Table 1. This data can assist the designer choosing the appropriate technology for the application. Any application sensitive to period jitter or frequency multiplication using PLL's should carefully consider these data when making a technology choice.

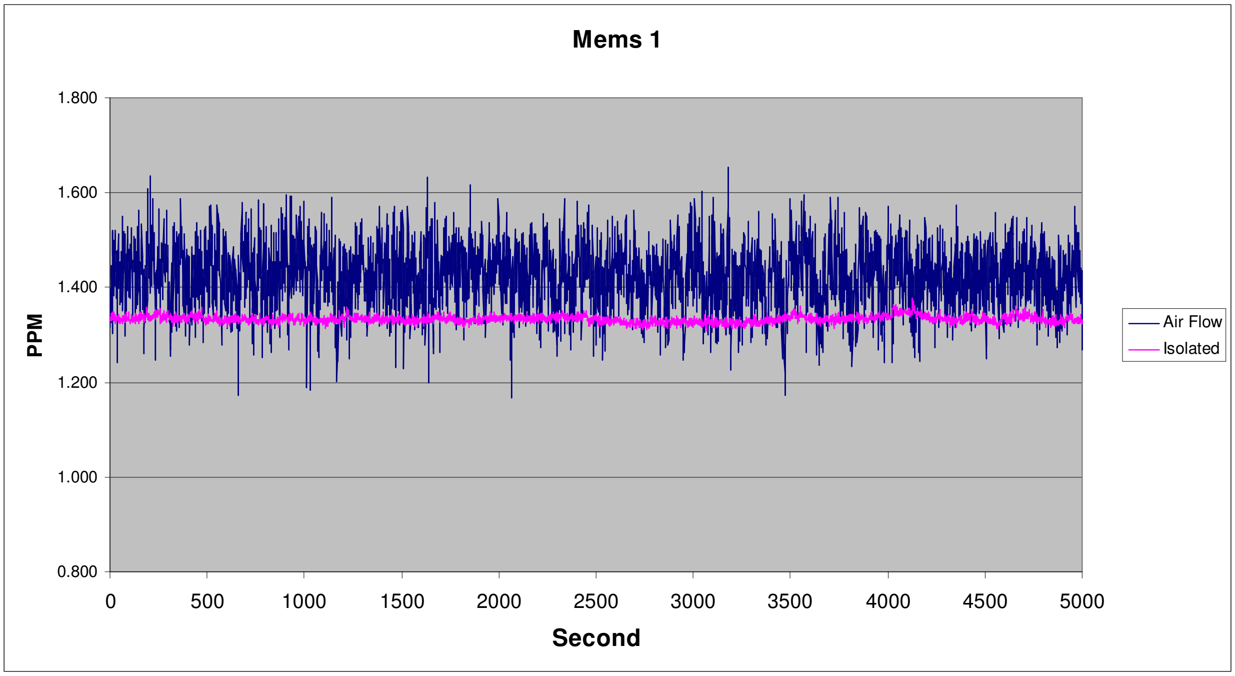

Fig # 7

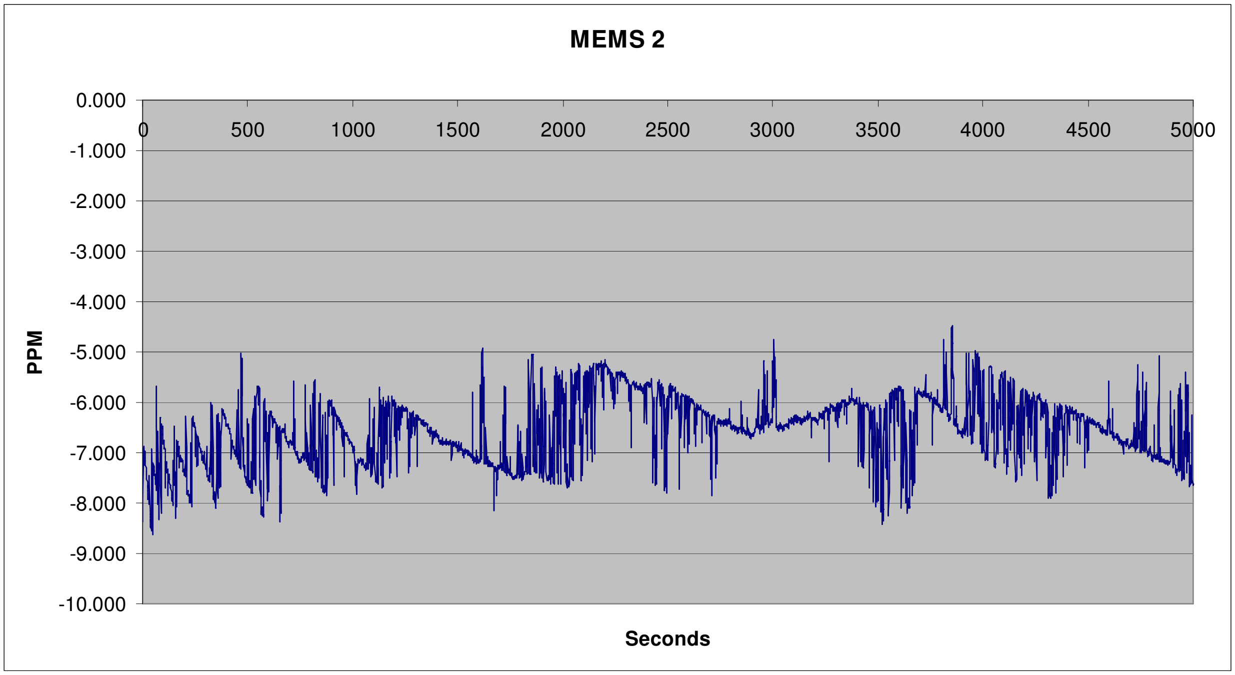
MEMS 2
0.000
-1.000
-2.000
-3.000
-4.000
-5.000
-6.000
-7.000
-8.000
-9.000
-10.000
PPM
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Seconds

Fig # 8

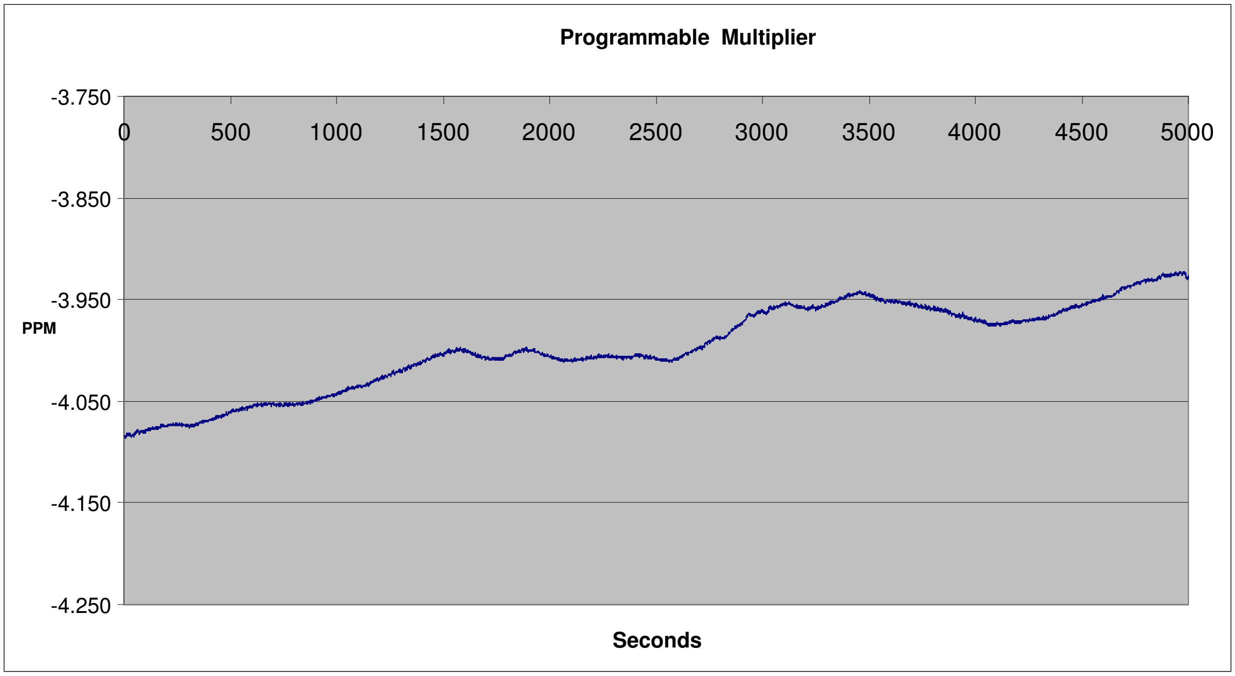
Programmable Multiplier
-3.750
-3.850
-3.950
-4.050
-4.150
-4.250
PPM
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Seconds

Fig # 9

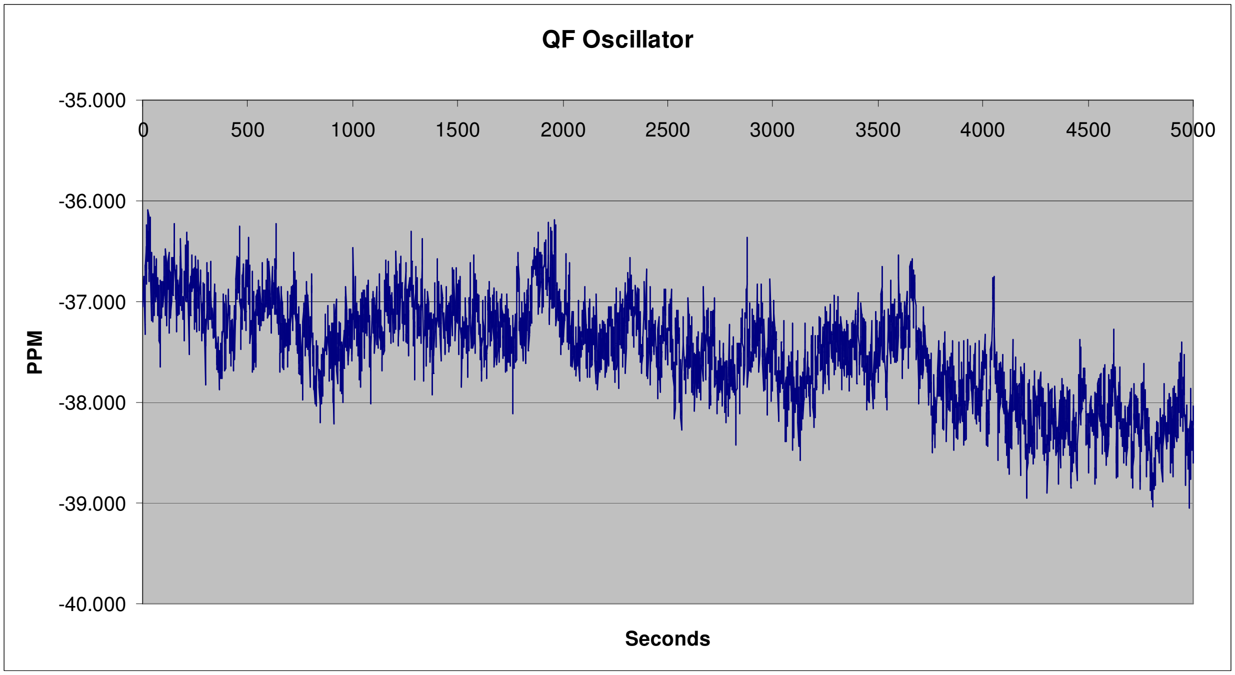

Fig # 10

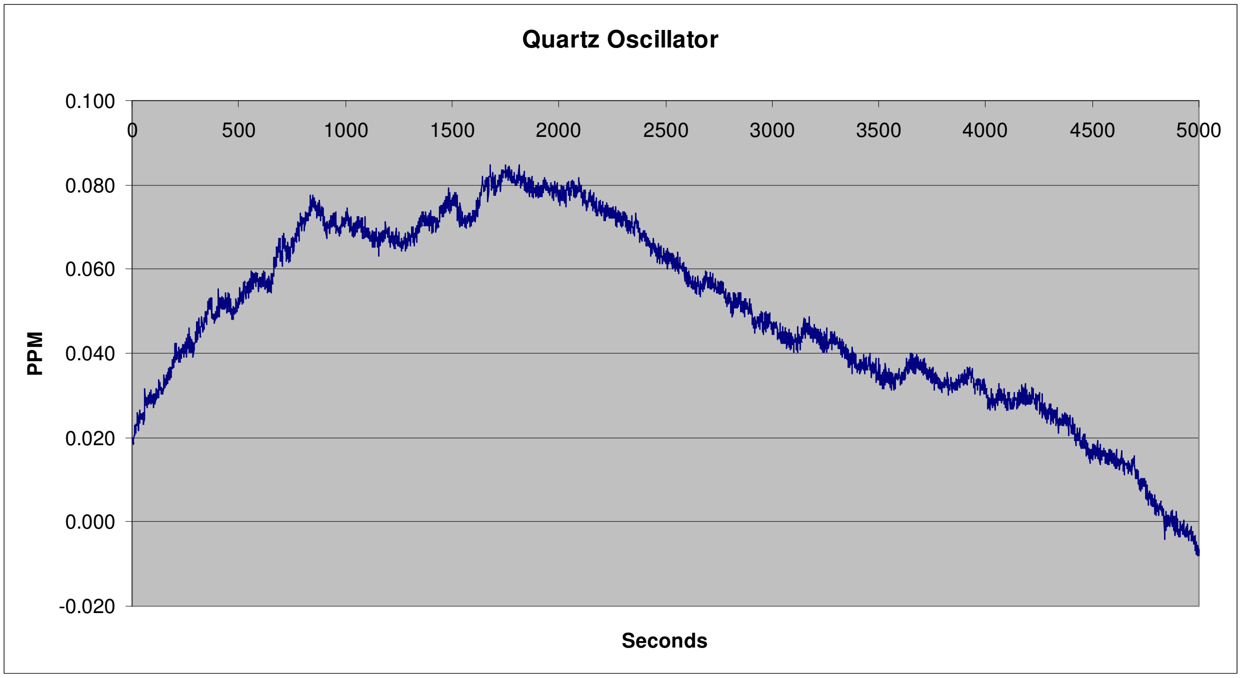

Fig # 11

NOTE: The digital compensation used in correcting the temperature coefficient of MEMS resonators seems to result in short-term frequency instability. Also, during our testing, the compensation scheme of MEMS oscillators appeared to make the short-term stability particularly more vulnerable to the changes in the surrounding environment. When MEMS I devices were exposed to disturbance caused by airflows induced by fans or waving hands, the short-term instability of the devices got much worse as shown in Fig. #7.

Table 1: Data Summary referenced to 25.0 MHz

Technology	**MEMS I Oscillators,**	**MEMS II Oscillators**	**Programmable Oscillators**	**QF Oscillators**	**Quartz Oscillators**
Hysteresis P-P	1.0 – 2.0 ppm	1.0 – 5.0 ppm	0.1 – 0.4 ppm	4.0 – 6.0 ppm	0.1 – 0.4 ppm
Jitter Over Full Bandwidth	23 pS	270 pS	4.1 pS	1200 pS	0.9 pS
Jitter over 12 kHz – 20 MHz	0.48 pS	250.1 pS	3.5 pS	1.0 pS	0.4 pS
Start-up Time	6.0mS @3.3V	2.15 mS @3.3V	0.1mS @3.3V	0.5 mS @3.3V	0.13 mS @3.3V
Supply Current	32 mA @3.3V	3.4 mA @3.3V	26.9 mA @3.3V	2 mA @3.3V	2.5 mA @3.3V
Short-term Stability	+/- 0.25 ppm	+/- 1.0-1.5 ppm	+/- 0.01 ppm	+/- 2.0– 3.0 ppm	+/- 0.004 ppm
Aging After 2,928 Hours	3 ppm*	-1.5 ppm	-0.9 ppm	15 ppm*	-0.8 ppm

Long-term Stability (Aging):

The long term stability means frequency drifts over a long period of time. The aging of most of the devices was measured over a period of 2928 hours. Most were aged passively at 105ºC, and then tested at 25 ºC in a temperature test chamber. The MEMS I and QF devices, marked with *, were actively aged at 85ºC for 840 hours. The initial delivery of these devices did not make it possible to age with the initial group. The Summary data are given in Table 1.

4. Non-electrical Characteristics

In addition to the electrical factors examined above, factors such as size, availability and cost may influence the selection of the frequency control technology. A comparison of these non-electrical factors for different technologies is shown in Table 2.

In terms of shock and vibration, quartz-free oscillators, which are basically semiconductor circuits without attendant resonators, are considered the most rugged, exceeding the performance of MEMS oscillators. As the size of the quartz resonators keeps shrinking, quartz oscillators are much less vulnerable to shock and vibration – most often far exceeding the needs of the application.

Table 2 Comparison of Non-electrical Characteristics

	MEMS I Oscillators	MEMS II Oscillators	Programmable Oscillators	QF Oscillators	Quartz-based Oscillators
Smallest Size Commercially Available	2.0 x 2.5 mm	2.0 x 2.5 mm	2.5 x 3.2 mm	2.5 x 3.2 mm	1.6 x 2.0 mm
Design cycle of New Frequencies	Faster since frequencies can be programmed.				May take weeks, but a vast repertory exists of frequencies already developed.
Estimated Unit Manufacturing Cost	Lower than quartz-based oscillators since only resonators of limited number of base frequencies are used and then programmed.			Lowest since no resonators are used.	Highest since a different quartz crystal design is used for each frequency. High volume prices for popular frequencies could be competitive.

5. Conclusions

The study discussed here and summarized in *Table 1* compared a number of different electrical characteristics of commercially available BAW, MEMS, PLL Programmable, and Quartz-free oscillators. The study results indicate that the different technologies are not interchangeable.

The performance of MEMS oscillators and QF oscillators in terms of phase noise, hysteresis, and short-term stability - key parameters in communications and high speed data/network applications - is still inferior to that of quartz-based oscillators. Consequently, MEMS oscillators and QF oscillators may be unacceptable in many of these applications.

Current draws can be significantly different among the different technology options. In battery-powered devices, this is typically a major concern. Long-term aging and start-up time may also be critical in some applications.

Applications that have complex modulation schemes, very-high-speed communication, or that require excellent signal-to-noise performance (for example, A/D converters) will continue to be clocked by BAW devices, taking advantage of the exceptionally high Q and excellent temperature vs. frequency stability of quartz.

Pletronics Inc. has taken every effort to acquire commercially available products and test the devices in a side-by-side comparison to benchmark the technologies. This is done to better educate our customer base on the advantages and disadvantages of the different frequency control technologies available.